Mine Burial Prediction: A Cooperative NRL/ONR Study

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LONG-TERM GOAL

Development of an accurate, real-time mine burial prediction capability by field testing and validation of an integrated, physics-based mine burial model.

OBJECTIVES

Sediment-structure interactions are responsible for the burial/penetration of heavy objects, such as bottom mines, pipelines, concrete breakwaters, and offshore platforms in the seafloor. On seabeds of low shear strength muds, these objects are known to penetrate on impact when the bearing capacity of the seafloor is exceeded, with additional subsequent burial from the sediment consolidation and creep. On sand seabeds, burial is common by scour and fill, momentary or cyclic wave-induced liquefaction, and seabed morphological changes (e.g., transverse bedform migration, changes in shore-rise and bar-berm conditions, sediment deposition). Using a field experimental approach, the Naval Research Laboratory (NRL) will test and evaluate physics-based mine burial processes and models in order to provide the US Navy with an accurate, real-time mine burial prediction capability.

APPROACH

NRL is tasked with development, deployment, and analyses of data from instrumented mines; conduct of impact burial experiments; development of an improved impact burial model; and development of an integrated mine burial model. One of the major problems in the experimental validation of mine burial models is the difficulty of continuous measurement of the behavior of the mine. Optically instrumented, cylindrical, subsequent burial mines, developed by NRL, provide a tool for continuous monitoring of the movement of the mine (heading, pitch and roll), as well as the percentage of the surface area of the mine actually buried (see Richardson et al., 2001; Griffin et al., 2001; Richardson and Traykovski, 2002). The next generation acoustically instrumented, subsequent burial mines were developed by OMNI Technologies Inc. under the direction of NRL as part of a Small Business Innovative Research initiative and will extend that monitoring capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the mine; measure sediment concentrations and flux in the vicinity of the mine; measure sea state and bottom currents; determine initiation of bed load transport; and calculate sediment transport (Griffin et al., 2002). An instrumented, cylindrical, impact burial mine was developed for impact burial experiments and is capable of monitoring mine motion during free-fall across the air-water interface, through the water

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column, and into the seabed sediments (three accelerations and three angular velocities) (Valent et al., 2001, 2002).

NRL leads the effort to improve the Impact Burial Prediction Model (IMPM) using data collected in tank and field tests during FY01-02 and is responsible for improving and validating the sediment penetration module and for integrating a hydrodynamic module and stochastic relevance into a final impact burial model. Field experiments on burial by scour and fill; bedform migration; bedform morphological alterations; liquefaction or fluidization of the sediment; and biological processes are scheduled for the winters of 2002-3 off Tampa Bay and 2003-4 at the Martha's Vineyard Coastal Observatory (MVCO). For all these experiments, NRL is responsible for: (a) deployment and analyses of data from instrumented mines, (b) quantification of environmental processes in the near field of the mine, and (c) characterization of mine movement and burial. These data will allow development and validation of new and proposed mine burial models.

Advances in our physical understanding of mine burial and the new mine burial models resulting from these joint experiments, including NRL modifications to the impact burial model, will be integrated into a framework for a stochastic approach to mine burial prediction. This model recognizes that mine or object burial is time dependent, spatially and temporally variable and that burial processes are not independent (Richardson et al., 2001). The integrated mine burial model will require as input: (a) wave climate and tidal and storm-induced bottom currents from in situ measurements or numerical oceanographic models, (b) sediment physical properties and small-scale morphological feature description from in situ measurements or historical databases, and (c) description of the anticipated mine threat. The model (preliminary version in 2003) will provide both strategic and tactical mine burial prediction. NRL will also assess the effects of uncertainties in the input parameters for predictions of mine burial at impact and by subsequent burial through stochastic simulations involving most free parameters. This differs from a sensitivity analysis where typically the effect of one variable is found throughout its variation. With stochastic simulations, all variables can vary and the model's convolution of the uncertainty through its nonlinearity can be addressed.

WORK COMPLETED

Martha's Vineyard Coastal Observatory Experiments:

Mine burial by scour and fill was characterized in real-time at MVCO using the optical instrumented, subsequent burial mine; acoustic Doppler velocimeter (ADV); bottom-mounted pressure sensors; and a sector scan sonar (see ONR FY02 report by co-investigator, Peter Traykovski, for additional details) (Fig. 1).

Impact Experiments off Corpus Christi, Texas:

Impact burial experiments were conducted during May 2002 on the continental shelf near Corpus Christi, Texas. NRL shared duties as chief scientist (Phil Valent, NRL with Wayne Dunlap, TAMU), provided diver support (6-man dive team) for the experiments, collected gravity cores for subsequent ship-board and laboratory analyses of sediment geotechnical and physical properties, measured in situ bearing strength with a STING penetrometer, and deployed the instrumented impact burial mine designed by NRL and OMNI Technologies.
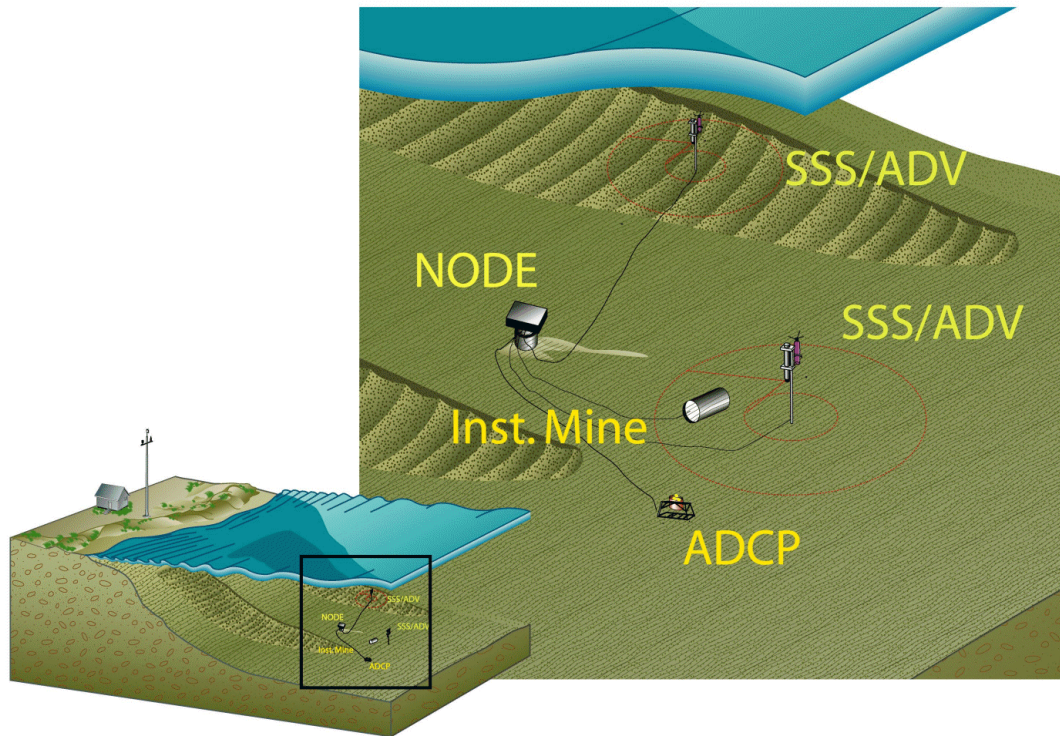
Figure 1. Cartoon of the relative location of the instrumented mine, sector scan sonars (SSS) with acoustic Doppler velocimeters (ADV), and acoustic doppler current profiler (ADCP) to the 12-m communication node at Martha's Vineyard Coastal Observatory. Sediment near the node consists of well-sorted, fine sand whereas sediment depicted as rippled is coarse sand and is 150 m from the node and mine burial instruments.

RESULTS

Martha's Vineyard Coastal Observatory Experiments:

Several episodic events of mine burial by scour-and-fill were observed during a 48-day experiment on a fine sand substrate in 12-m water depth at the MVCO. Mine behavior was documented with an instrumented mine and with images from a sector scanning sonar. Like blind men observing an elephant, each set of sensors provides different, yet complementary, views of the mine burial process. Sensors in the instrumented mine accurately record mine movement (pitch, roll and heading) and percent of the mine surface covered with sediment. The sector scan sonar provides detailed information on seabed elevation, character of the seafloor surface, the elevation of the mine relative to the bed, and the spatial development of the scour pit. During the experiment, scour, predominately around both ends of the mine, occurred rapidly (1-6 hours) in response to increases in the significant wave height and the period of surface gravity waves. When the remaining central sand pedestal was insufficient to support the mine, the mine rapidly pitched and rolled into the scour pit, possibly changing heading to match the incoming swell. This reorientation occurred within a few minutes. Then, over the next few days of decreasing wave energy, the scour pit around the mine slowly filled

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with sediment and the mine was more deeply buried. These events were repeated until the mine was completely buried.

Scour around the mine tended to occur when significant wave heights exceed 1.5-m, when bed stresses exceeded 5-8 dynes cm^{-2} from bottom wave orbital velocities in excess of 30 cm s^{-1}. Evaluation of burial data from MVCO suggests a conceptual model whereby the amount of energy required to further bury the mine during a storm is dependent on how deeply it has been buried by previous storms. In order for a mine to roll into the scour pit, the pit must become deeper than the lowest surface of the mine. Thus, if the mine has been partially buried by a previous storm, it requires at least as much energy than that applied in the previous storm to enlarge the scour pit to the point where additional elevation changes of the mine are possible. Complete mine burial and the final depth of mine burial, as in our experiment, may be enhanced by local or regional changes in bed elevation.

In the first MVCO experiment, a time-scaling, scour-burial-model-based amplification of sediment transport around the mine modified by infilling was found to accurately predict mine burial. The bottom wave orbital velocity measured at the seafloor using the ADV was similar to orbital motion predicted from wave height and period derived from a NOAA regional wave model (WaveWatch III). These experiments and model comparisons suggest burial by scour can be accurately predicted from sediment type (mean grain size), bathymetry, mine characteristics, and measured or model predicted wave statistics and bottom currents.

Analysis of mine burial will continue with data collected during the second MVCO deployment of the instrument mine and sector scanning sonar on fine grained sediment (5 April – late May 2002). A third and possibly fourth deployment of these instruments is planned for the coarse sand sediment during the winter of 2002-3. These data will provide a unique, high fidelity set of mine burial and environmental data to test and evaluate scour mine burial processes and to test mine burial models.

Impact Burial Experiments Off Corpus Christi, Texas:

The motion of the instrumented impact mine, from the moment of deployment through embedment in the seafloor, was characterized using data collected from the 3-axis fiberoptic gyro (roll, pitch and heading) and 3-axis accelerometers and magnetometer. NRL has recently developed software to analyze the sensor data describing this complex motion (Theophanis et al., 2002). Mine trajectory, velocity and orientation data will be given to ONR modelers as soon as quality control of the data is complete. Sediment cores were logged (sound speed, attenuation and bulk density) at the NRL laboratory facilities, undrained miniature vane shear strengths measured, and subsamples collected for measurement of sediment natural water content. These sediment physical and geotechnical properties, together with the 6-degrees of freedom motion of the mine, will be used to evaluate predictions of the current impact burial model (IBPM 28). During FY03 the laboratory work on sediment cores will be completed, data summarized, mine trajectories calculated, and all data provided to ONR scientists. Preliminary results were published as a proceedings paper for the 5th International Symposium Technology and the Mine Problem held in Monterey, CA (April 2002) (Valent et al., 2002). Results will be published in peer-reviewed journals. Techniques used to characterize the 3-dimensional motion of the mine with 6-degrees of freedom have been submitted to IEEE-OE. A second set of impact experiments is tentatively planned for the summer of 2003. These experiments will be directed towards the characterization of penetration of the mine into soft cohesive (mud) sediment.

IMPACT/APPLICATIONS

Buried mine detection has been and is still one of the greatest threats facing shallow water Mine CounterMeasures (MCM) operations. The possible presence of buried mines can change MCM tactics from mine hunting to minesweeping or area avoidance. The ability to predict mine burial both for planning and during operations (strategic and tactical scenarios) is therefore of great importance to Naval forces.

TRANSITIONS

At the completion of the joint ONR/NRL experiments a fully operational, integrated, physics-based mine burial model will be transitioned to NAVOCEANO. In the interim, fully operational instrumented mines (impact and subsequent burial mines) will be completed, tested and used as part of the ONR mine burial experimental program. Impact mines will allow characterization of the full 6-degrees of freedom motion (three linear and three angular displacements as functions of time) thus monitoring mine motion across the air-water interface, through the water column, and penetration into sediments. Various cylindrical mine configurations (mass, mass distribution, nose types) will be considered. Instrumented mines designed for subsequent burial will allow characterization of mine movement (pitch, roll, and yaw), percentage of the surface area of the mine buried, as well as provide the capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the mine; measure sediment concentrations and flux in the vicinity of the mine; measure sea state and bottom currents; determine initiation of bed load transport; and calculate sediment transport. A new impact mine burial model with corrections to the hydrodynamic module will be transitioned to NAVOCEANO.

RELATED PROJECTS

All ONR projects in the Mine Burial Prediction Program

REFERENCES

Richardson M.D. and K.B. Briggs. 2000. Seabed-Structure Interactions in Coastal Sediments. *Proceedings of the 4th International Symposium on Technology and the Mine Problem*. Naval Postgraduate School, Monterey California, 13-16 March 2000.

Richardson, M.D., P.J. Valent, K.B. Briggs, J. Bradley, and S. Griffin. 2001. NRL Mine Burial Experiments. Proceedings of the Second Australian-American Joint Conference on Technologies of Mine Countermeasures, Sydney Australia, 27-29 March 2001. Defence Science and Technology Organization.

Valent, P.J., K.B. Briggs, M.D. Richardson, J. Bradley, S. Griffin and D.C. Young. 2001. Field Experimental Evaluation of the Mine Impact Burial Prediction Model. Abstract for poster presented at the Second Australian-American Joint Conference on Technologies of Mine Countermeasures, Sydney Australia, 27-29 March 2001.

PUBLICATIONS

Briggs, K.B.. P. Elmore, C. Friedrichs, M.D. Richardson and P. Traykovski. 2002. Predicting Mine Burial at the Martha's Vineyard Coastal Observatory. Eos fall meeting.

Griffin, S., J. Bradley, M.D. Richardson, K.B. Briggs and P.J. Valent. 2001. Instrumented mines for mine burial studies. *Sea Technology,* **42 (11)***:21-27.*

Griffin, S., J. Bradley, M. Thiele, C. Tran, F. Grosz, and M. D. Richardson. 2002. An improved subsequent burial instrumented mine. Accept for MTS Oceans 2002).

Richardson, M.D. and P Traykovski. 2002. Real-time observations of mine burial at the Martha's Vineyard Coastal Observatory. 11 pps.. *Proceedings of the 5th International Symposium on Technology and the Mine Problem*. Naval Postgraduate School, Monterey California, 22-25 May 2002.

Theophanis, S. W. Shi, P. Valent, G. Bower, M.D. Richardson, C. King, C. Kennedy, and J. Bradley. Accelerometer and fiber optic gyro measurements of an instrumented mine used to study impact burial. IEEE (submitted).

Traykovski, P. and M.D. Richardson. 2002. Observations of Bedforms and Mine Burial Processes. Eos fall meeting.

Valent, P.J., K.T. Holland, A.W. Green. S. Theophanis, M.D. Richardson, G.D. Bower, P. Congedo and W. Lewis. 2002. Observations of velocities and orientation of cylindrical bodies at terminal condition in water. *Proceedings of the 5th International Symposium on Technology and the Mine Problem*. Naval Postgraduate School, Monterey California, 22-25, May 2002.

PATENTS

None.